ATTORNEY DOCKET NO.: N. DAGDEVIREN 18 PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Nuri R. Dagdeviren

Serial No.: 09/540,475

Filed: March 31, 2000

Title: PRECODING FOR A NON-LINEAR CODEC

Grp./A.U.: 2637

Examiner: Guillermo Munoz

Commissioner for Patents
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I hereby certify that this correspondence is being deposited with the United States Postal Service as first class mail in an envelope addressed to: Commissioner for Patents, Alexandria, VA 22313, on 02/28/05 (Date)
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Sir:

AFFIDAVIT UNDER 37 C.F.R. §1.131

I, Nuri R. Dagdeviren, hereby state:

1. I am the inventor of the claimed subject matter in the Patent Application identified above and the inventor of the subject matter described therein.

2. Prior to November 29, 1999, I conceived precoding an input signal to generate a mapped constellation signal, as covered by the above-identified Patent Application, as evidenced by the following:

a. I submitted a technical paper disclosing conception of the invention prior to November 29, 1999, and after the date of conception. A true and correct copy of this technical paper

is attached hereto as Exhibit A. Thereafter, I participated in preparing information necessary for subsequent filing of a provisional patent application, which was diligently prepared and filed with the United States Patent Office on December 29, 1999, and the above referenced Patent Application in the United States, which was diligently prepared and filed with the United States Patent Office on March 31, 2000.

b. Any dates omitted from Exhibit A are prior to November 29, 1999.

I declare further that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the Application or any patent issuing thereon.

Nuri R. Dagdeviren

Date: Feb. 28, 2005

EXHIBIT A

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Precoding for a Non-Linear Codec

Abstract

This invention is related to "56k" modem technology. Specifically it proposes a new precoding scheme to achieve rates higher than 33.6 in the analog modem to digital modem direction.

Introduction

Tomlinson[1]-Harashima[2] precoding (THP) has emerged as an attractive solution for equalization in the presence of severe channel attenuation in the frequency band of interest. It is equivalent to Decision Feedback Equalization[3] (DFE) in the receiver without the potential problem of error propagation.

One popular application with a zero in the band of interest is "56k" modems[4]. The zero at zero frequency comes from the transformer coupling of the subscriber loop to the central office equipment. Therefore, telephone lines do not pass DC signals. Low frequencies near DC are also attenuated significantly as to rule out linear equalization of this channel. It is not possible to avoid the zero at DC for 56k modems using pass-band modulation as in the case of earlier V.34 modems because the central site modem is limited to using the sampling rate and quantization levels of the PCM codec at the central office. It is not possible to modulate a base band signal into a pass band while remaining within the constraints of a PCM codec.

One possible way to equalize this channel is to use a linear equalizer to reduce the channel response to a simpler "partial" response[5] that still possesses the zero in the channel but can be dealt with using a non-linear technique such as maximum likelihood sequence (MLSE) decoding or decision feedback equalization. This however is only possible in the direction of digital modem to analog modem, also referred as the downstream direction. The reason this approach or any linear equalization scheme does not work in the upstream direction is that only PCM codec levels themselves can pass through the PCM codec unscathed. Any filtered version of a sequence PCM levels will be a linear combination of these levels and in general not be a PCM level itself. When such intermediate levels are quantized by the PCM codec, quantization noise is introduced into the signal erasing any advantage over V.34 techniques.

One way to overcome this difficulty is to use precoding in the transmitter in place of MLSE or DFE in the receiver. In this way PCM levels can be used as the symbol constellation. The combination of the precoder and the linear equalizer will eliminate the inter-symbol interference (ISI) introduced by the channel. In this manner signals arriving at the PCM codec will be free of ISI and no quantization noise will be introduced.

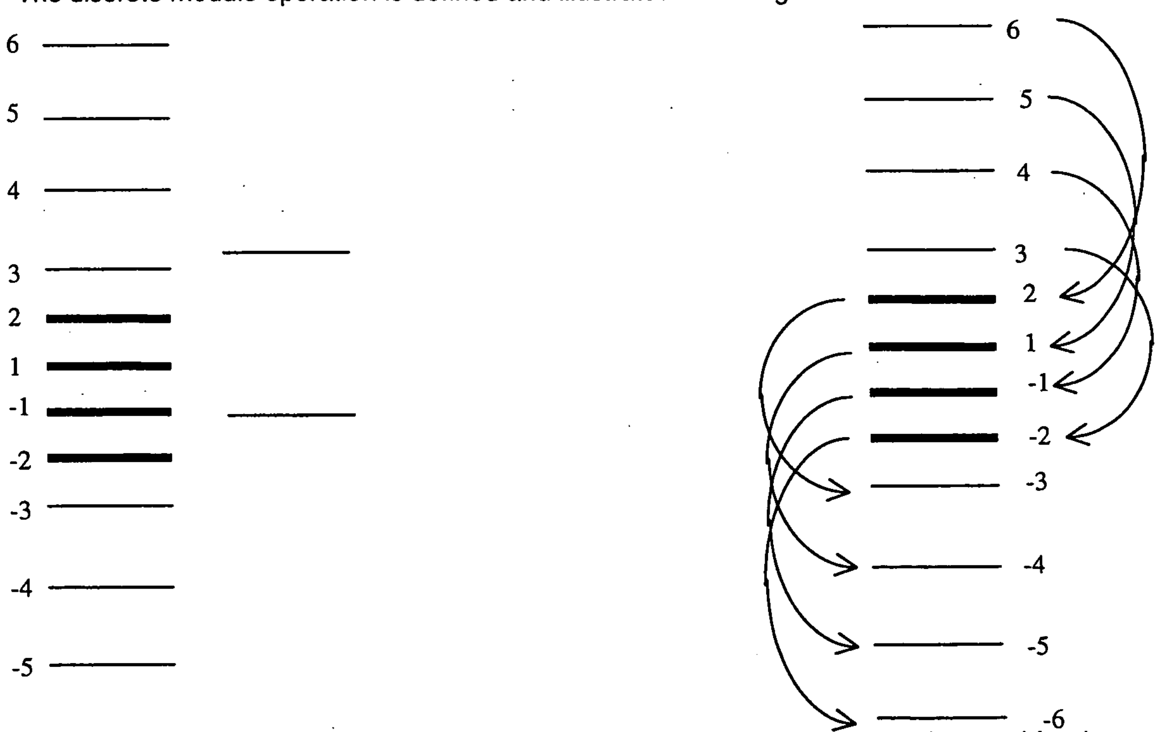
The simplest manner of implementing precoding is to implement a feedback filter that equalizes the partial response. This however is not practical in the case where the channel and hence the

partial response possesses a zero in the band of interest. The reason is that since the feedback filter equalizes the partial response, it has a very large gain at the frequency where the partial response has a zero. Components in the transmitted signal that correspond to this frequency will be greatly amplified leading to an unstable feedback loop.
The clever solution to this problem is provided in the THP as follows. Whenever the output of the feedback loop passes a preset threshold, the transmitted signal is subjected to a modulo operation which brings it to within range. This removes the instability in the feedback loop of the transmitter. This trick has an effect on the receiver as well which needs to be accounted for. Since the modulo operation can be expressed as the addition of a constant, the receiver will have to compensate by subtracting the constant from the received signal. The receiver will know when to do this because whenever the transmitter subtracts the constant to bring the transmitted value to within range, the received value in the receiver will be out of range and the receiver will add the constant back to bring the signal to within range.

It is not possible to implement the THP scheme in a PCM modem in the upstream direction because the receiver can not implement the modulo compensation without introducing quantization noise. If the transmitter implements the usual THP modulo operation, then the received signal will arrive at the PCM codec with a value that corresponds to a PCM value shifted by a constant. In general it is not possible to find a set of PCM values and a constant such that each PCM value, when shifted by a constant is another PCM value. Thus THP scheme as previously defined can not be used for PCM modems.

This invention modifies the THP algorithm as commonly used to adapt it for use in PCM modems. Instead of arithmetic modulo operation that is implemented in the transmitter we define a discrete modulo operation as a function of the constellation chosen. This operation performs the function of limiting the amplitude of the transmitted signals, hence removing the instability of the feedback loop while ensuring that recevied signals at the PCM codec are always within the PCM level set free of quantization noise. Similarly a discrete modulo operation is defined for the receiver to map received PCM values correctly into the symbol constellation.

The discrete modulo operation is defined and illustrated in the Figure below.



The discrete modulo operation is defined with respect to the constellation to be used for data transmission. The basic constellation used {2,1,-1,-2} is matched with a constellation of equal size consisting of negative levels {-3,-4,-5,-6} that is one-to-one mapped with the basic

constellation as well as another consisting of positive values {3,4,5,6}. Whenever the receiver in the digital modem receives a level in the positive or negative constellations, it maps the level to the corresponding level in the basic constellation. This mapping in the receiver can be formulated as a shift operation that is dependent on the level being transmitted. If the difference between the level j in the basic constellation and the corresponding level in the negative constellation is n_j then the mapping in the receiver from the negative constellation can be thought of as an addition of offset n_j to the received value. Similarly if the corresponding distance with the level in the positive constellation is p_j this can be thought of as a subtraction of p_j from the received value. The transmitter, aware of this behavior in the receiver, performs the opposite function prior to transmission. Whether the an addition or a subtraction is performed in the transmitter depends on the whether the output of the feedback filter is greater than the maximum value in the constellation or smaller than the minimum value in the basic constellation. The operation of the complete system can be specified as follows:

The transmitter:

If the output of the feedback filter is larger than the maximum of the basic constellation and level j is transmitted then subtract n_j from the transmitted value

Else if the output of the feedback filter is smaller than the minimum of the basic constellation and level j is transmitted then add p_j to the transmitted value

Otherwise transmit the output of the feedback filter as is,

The receiver:

Map received levels in the positive and negative constellations to the corresponding values in the basic constellation

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[1] M. Tomlinson "New Automatic Equalizer Employing Modulo Arithmetic" Electronics Letters. Vol.7, pp. 138-139 March 1971

[2] H. Harashima and H. Miyakawa " Matched-Transmission Technique for Channels with Intersymbol Interference" IEEE Trans. Commun. vol. COM-20, pp. 774-80, August 1972

[3] C.A. Belfiore and J.H. Park " Decision Feedback Equalization" Proceedings of the IEEE 67(8), August 1979

[4] U.S. Patents 5,394,437 5,406,583 5,528,625 5,831,561
I.Kalet, J.E. Mazo, and B. Saltzberg " The Capacity Of PCM Voiceband Channels" Proc. IEEE International Conference On Communications '93 pp. 507-511 , July 1993
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[5] Lee and Messerschmitt " Digital Communications" Kluwer Academic Publishers